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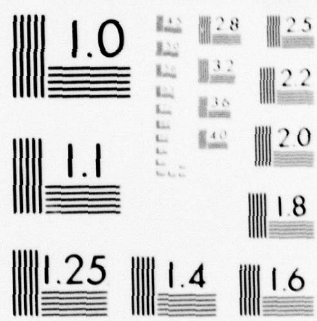

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THE TESTING OF LIQUID FUEL ROCKET ENGINE

by

Fan Shun Fa

FOREIGN TECHNOLOGY DIVISION

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THE TESTING OF LIQUID FUEL ROCKET ENGINE

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THE TESTING OF LIQUID FUEL ROCKET ENGINE

Fan Shun Fa

One very important phase of the research and development of a rocket engine is testing, which is also one of the methods to evaluate the product quality. As rocket engine testing is an involved and complex procedure, this article will only introduce the general concepts of testing methods and the facilities of a liquid fuel rocket engine testing station.

It is well known that rocket engines have found increasingly wide applications in powered flights; they serve as power systems of various types of military missiles and rockets, and in civilian applications, they power space ships and earth satellite carriers. When you see a stalled automobile on the highway, you might wonder if rocket engine malfunction can fail a missile on its way to an enemy target or a launched satellite. This is indeed possible. In order to prevent such failure, reliable high quality engines are needed as the power device. To ensure the engine's quality, thorough and rigorous tests and evaluations are carried out in the development and production stages.

WHY THE TESTS?

A rocket engine is a complicated heat engine with many interrelated parameters. It is exceedingly difficult to guarantee high performance and reliable operation based on theoretical calculations alone, hence the numerous and repeated testings. During the tests, engine characteristics

are sought and used in adjustments and further improvements of the engine's performance. Engine parts, workmanship, and operation consistency are closely scrutinized and the accuracy of design theory is checked. It is essential to go through a sequence of tests before a rocket engine is put to use.

Tests performed on an unignited rocket engine is generally referred to as the "cold run." "Hot run" then refers to the tests with propellant introduced into the generator or propulsion chamber and ignited. Based on cold tests, the hot run obtains engine characteristics parameters and reliability data under conditions close to the actual operating situation. Because of the elaborate facility required and the high costs, hot tests are usually performed to supplement cold runs or in over-all evaluations. The hot tests under stationary conditions of liquid fuel engines will be discussed below.

TEST CONTENTS AND METHODS

Liquid fuel engine stationary state hot tests are performed with the engine fixed on the testing frame which supplies the propellant needed in ignition tests and also collects operating parameters. Generally speaking, rocket engines go through three different types of tests before use: research tests, calibration and specification tests, and production tests.

Research tests are basically scientific in nature and cover a wide variety of items. Through repeated tests of components and the entire engine, information on the proper choices of design parameters, main characteristics, operation consistency and possible defects are obtained. Research tests also include simulation tests under certain

preset conditions such as high temperature, low temperature, vibration, overload, humidity and rain, and vacuum.

Adjustment and calibration runs are made on engines of new or modified design. First, the performance parameters are adjusted to agree with the technical requirements set by the design, and then, the engine is mounted on the rocket and coordinated with the supply system and control system under a stationary state. The challenge of flight tests comes next. If all the design requirements are met in the above tests, the specification of the engine will be established. This includes design blueprints, performance parameters, manufacturing processes, and raw material choices. After establishing the specification, batch production will begin.

For batch produced engines, tests will be carried out on components and whole engines for manufacturing quality. Since most rocket engines are designed for one time use only, such tests are usually sample checks. Spot checks are made according to the determined specifications and allowed tolerances on such fundamental factors as thrust, flow rate, pressure and working time. If samples are within specifications, the entire batch is considered satisfactory, otherwise, the number of samples is allowed to double and the batch is still considered satisfactory if doubled sample tests are within specifications. If not, the entire batch is rejected.

TEST STATION FACILITIES

Rocket engine testing facility varies from relatively simple to elaborately complex, the latter being the case for large liquid fuel rocket engines. During the test, the engine delivers substantial thrust

(tens, hundreds or even one thousand tons), and the combustion procedures flames of tens or up to hundred meters in length and exceeds 2000°C in temperature, with high level noise accompanying the above. All these caused great difficulties to the equipment and structure of the testing station and imposes stringent requirements on industrial and occupational safety. In the following sections, we will briefly discuss several aspects of test facilities.

1. Types of testing stations.

Testing stations can be classified into large type, medium type, and small type according to the rocket engine thrust; or divided into liquid type, solid type, liquid/solid type, nuclear type, and electric propulsion type according to the different propellants used by the engine. They can also be categorized into space-simulation type, surface type and under water type according to the engine's working conditions.

2. Types of station construction.

The main components of different types of testing stations are approximately the same, while their construction has a somewhat greater variety. The main components include the thrust testing frame on which the engine is mounted, the propellant supply system, data acquisition system and control system. The instrumentation of systems and building structure are collectively referred to as the testing station. A testing ground includes the additional living quarters of the technical personnel and supporting staff with facilities like water, electricity, gas, communications, fire prevention, maintenance, warehouse, cafeteria, dormitory and so on.

The engines can be mounted horizontally on the testing frame

(Figure 1) or vertically as in Figure 2, or inclined. The testing room can also be of the open type or the closed type. The open type testing

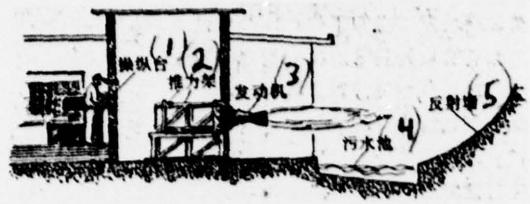

Fig. 1. Horizontal Testing Station

Key: 1- Control Booth 2- Thrust Frame 3- Engine 4- Waste Water Pool
5- Reflection Wall

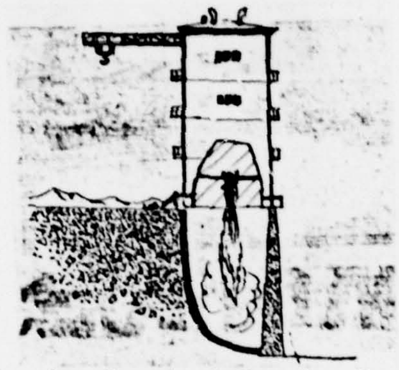

Fig. 2. Vertical Testing Station

room has the frame-mounted engine within a building with one to three open sides; and the closed type has it in an enclosed building with sound absorbing and first-aid equipments. The structure of a testing station is determined mainly by the size and use of the engine under test; generally speaking, open structure and vertical frame mounting should be used for medium to large size engines, and a closed type structure with horizontal mount is appropriate for small engines. Now let us examine two examples:

Suppose the thrust does not exceed five tons, the test station can adopt the configuration shown in Fig. 1. With the engine mounted horizontally on the thrust test frame, storage tanks of the propellant system and control and monitoring facilities can be along the sides or in the rear

where they are separated from the engine by explosion proof concrete walls. A reflection wall can be installed in the direction of the flame.

If the thrust is more than a few tens or one hundred tons, the vertical type of Fig. 2 should be used. In this arrangement, the danger of explosion due to accumulated fuel is low. As a safety precaution, the various components in the testing station should be kept apart from each other. The supply system storage tanks of propellant should stand alone in the building and the control and observation room should be the farthest away from the test frame. To prevent structural damage due to the exhaust flame, the station should have an engine mounting frame of adequate height or be built on a hill of steep slope. An exhaust deflector should be installed and water sprayed to the center of the flame for cooling and noise reduction. This type of station should be away from residential areas.

3. Safety considerations

In the process of rocket testing, accidents may occur in the handling of dangerous propellant and in controlling the combustion at high temperature and pressure; therefore strict safety regulations must be observed in the construction and operation of testing stations. For the station lay-out, there should be adequate safety distances between the testing frame, propellant storage tanks, control room and the main warehouse structure. Building structure should be explosion and fire-proof and personnel should be within protected rooms. Whenever possible, control and observation should be operated remotely and data recorded automatically. Sufficient fire fighting and warning systems should be installed and complete safety equipments provided for the testing personnel. Safety rules must be established in the organization and

enforced with rigor. In addition, industrial waste water treatment should also be taken into consideration.

CHECKS DURING TESTS

The performance parameters generally measured in rocket testing include thrust, flow rate, pressure and operation time, from which such quantities as thrust ratio and mixture ratio are determined after data reduction. Measurements can be done either directly or indirectly. Some data are taken using common equipment and method; other measurements, specifically pertaining to rocket engine testing, must be conducted using special instruments. The equipment and technique for measuring three of the important parameters are now described below.

Thrust Measurement: This device continuously records the thrust developed by the engine which is transmitted through a movable frame to the gauge. Frequently used gauges are hydrolic gauge, spring force gauge and resistance wire type gauge. The piston in a cylinder converts thrust to pressure in the hydrolic force gauge, as shown in Fig. 3. A calibration device is needed to verify the scale (such as 100 Kg, 1 ton, 2 tons, etc.) of the thrust gauge, or to bring the accuracy with the specification before tests begin.

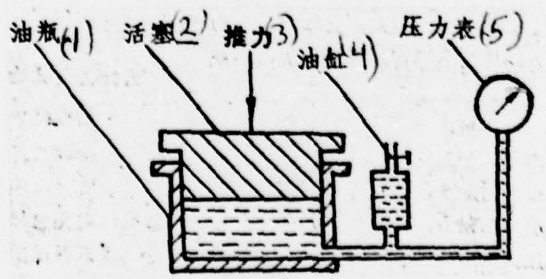

Fig. 3. Hydrolic Pressure Gauge

Key: 1- Oil Reservoir 2- Piston 3- Thrust 4- Oil Tank 5- Pressure Gauge

The accuracy of tests relies on the accuracy of calibration devices. As an example, we often use a micrometer in the shop to check whether the dimensions of a machined piece are in agreement with the drawing. The micrometer is more accurate than a ruler or a calliper; however, there are always two sides to everything, and for various reasons the micrometer has its error too. To ensure the accuracy of the micrometer, it must be calibrated against some still more accurate device. By using calibration devices of various degrees of higher accuracy, the micrometer accuracy is improved and its measurements would reflect reality more closely. For the same token, high accuracy calibration devices are needed to improve the rocket engine parameter measurements.

Flow Measurement: This measurement ascertains the propellant consumption within unit time during the engine test. In this method, a throttle (such as perforated plate, nozzle or Venturi tube) is installed in the pipe where flow rate is to be determined. Turbo-flow gauge or other types of flow gauge can also be used. The simple difference pressure gauge of the perforated plate type is shown in Fig. 4. In this arrangement, the increased flow speed due to the restricted cross area near the throttle

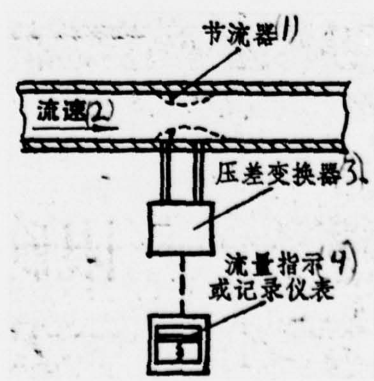

Fig. 4. Flow rate gauge of the perforated plate type

Key: 1- Throttle 2- Flow Speed 3- Difference Pressure Converter
4- Flow Rate Gauge of Recorder

results in a pressure difference before and after the throttle. Since the flow rate is proportional to the square root of the pressure difference, the rate of fluid flow through the throttle can thus be determined by merely measuring the pressure difference and performing a conversion calculation.

Pressure Measurement: The working pressure of the main components of the engine during a hot run is measured. These pressures are closely linked to the engine performance. Commonly used pressure transducers have the following different types: spring, induction, potentiometer, capacitor, and strain resistance. What is a pressure transducer? Simply put, a pressure transducer is an element which changes pressure, a non-electrical quantity, to an electrical quantity. For example, the strain resistance type pressure transducer converts variations in pressure to corresponding variations in resistance, which in turn is converted to a voltage signal through the action of a bridge circuit. The output voltage signal then drives meters or recorders to indicate pressure data.

Additional parameters such as temperature, stress, vibration and combustion gas composition will not be discussed here.

In recent years, with new or more demanding challenges arising from rapidly progessing rocket technology, testing techniques and equipments have been going through continuous innovation and improvement. We should broadly investigate the rocket engine testing techniques in depth, and in the meantime, establish sensible guidelines for testing projects to reduce the number of tests and improve reliability. Let us build up our testing grounds and organizations to carry out the task economically and efficiently.

Figures by Li Chia

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